

See discussions, stats, and author profiles for this publication at: <https://www.researchgate.net/publication/366539331>

The Sound of Bells in Data Cells – Perceived Quality and Pleasantness of Church Bell Chimes

Conference Paper in Proceedings of meetings on acoustics Acoustical Society of America · December 2022

DOI: 10.1121/2.0001661

CITATION

1

READS

136

8 authors, including:



Christoph Reuter

University of Vienna

291 PUBLICATIONS 451 CITATIONS

[SEE PROFILE](#)



Michael Plitzner

Kempten University of Applied Sciences

6 PUBLICATIONS 1 CITATION

[SEE PROFILE](#)



Marik Roos

University of Vienna

40 PUBLICATIONS 4 CITATIONS

[SEE PROFILE](#)



Isabella Czedik-Eysenberg

University of Vienna

118 PUBLICATIONS 133 CITATIONS

[SEE PROFILE](#)

The Sound of Bells in Data Cells – Perceived Quality and Pleasantness of Church Bell Chimes

Christoph Reuter, Michael Plitzner, Marik Roos, et al.

Citation: *Proc. Mtgs. Acoust.* **49**, 035006 (2022); doi: 10.1121/2.0001661

View online: <https://doi.org/10.1121/2.0001661>

View Table of Contents: <https://asa.scitation.org/toc/pma/49/1>

Published by the [Acoustical Society of America](#)

ARTICLES YOU MAY BE INTERESTED IN

[How can we approach the topic of the tone-to-tone timbre variability of historical instruments?](#)

Proceedings of Meetings on Acoustics **49**, 035005 (2022); <https://doi.org/10.1121/2.0001660>

[Identification of violin timbre by neural network using acoustic features](#)

Proceedings of Meetings on Acoustics **49**, 035004 (2022); <https://doi.org/10.1121/2.0001659>

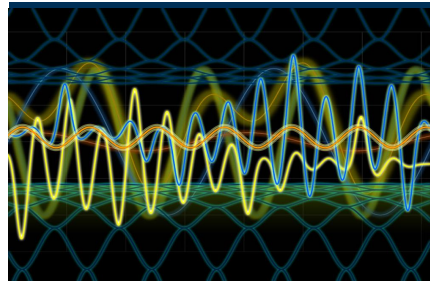
[Regime-change-induced modification of jet flow in flute-like instruments with a hysteresis region](#)

Proceedings of Meetings on Acoustics **49**, 035003 (2022); <https://doi.org/10.1121/2.0001657>



Why Publish in POMA?

Watch Now 



Fourth Vienna Talk on Music Acoustics

University of Music and Performing Arts

Vienna, Austria

11-14 September 2022

Musical Acoustics: Poster Session 5

The Sound of Bells in Data Cells – Perceived Quality and Pleasantness of Church Bell Chimes

Christoph Reuter

Musicological Department (Systematic Musicology), University of Vienna Faculty of Philological and Cultural Studies: Universitat Wien Philologisch-Kulturwissenschaftliche Fakultät, Vienna, Vienna, 1090, AUSTRIA; christoph.reuter@univie.ac.at

Michael Plitzner

European Competence Center for Bells, ECC-ProBell, University of Kempten, Kempten, Bavaria, 87435, GERMANY; michael.plitzner@hs-kempten.de

Marik Roos

Musicological Department (Systematic Musicology), University of Vienna Faculty of Philological and Cultural Studies, Vienna, 1090, AUSTRIA; marik.roos@univie.ac.at

Isabella Czedik-Eysenberg

Musicological Department (Systematic Musicology), University of Osnabrück, Osnabrück, Niedersachsen, 49074 GERMANY; isabella.czedik-eysenberg@univie.ac.at

Veronika Weber

MediaLab, University of Vienna Faculty of Philological and Cultural Studies, Vienna, 1090, AUSTRIA; veronika.weber@univie.ac.at

Saleh Siddiq

Musicological Department (Systematic Musicology), University of Vienna Faculty of Philological and Cultural Studies, Vienna, 1090, AUSTRIA; saleh.siddiq@univie.ac.at

Michael Oehler

Musicological Department (Systematic Musicology), University of Osnabrück, Osnabrück, Niedersachsen, 49074 GERMANY; michael.oehler@uos.de

Andreas Rupp

European Competence Center for Bells, ECC-ProBell, University of Kempten, Kempten, Bavaria, 87435, GERMANY; andreas.rupp@hs-kempten.de

According to guidelines for the evaluation of church bell chimes, the timbre of a well-sounding bell is characterized by a soft, full, bright and clear tone with a salient fundamental pitch in a low-noise sound spectrum, where a luminous, clearly pronounced striking tone can be heard with as little percussive noise as possible. In a pilot experiment, 11 bell experts and 26 laypersons evaluated the ringing of 40 loudness-matched bell recordings in terms of tonal quality, pleasantness, salience of the fundamental pitch, clarity and softness of the attack. Via signal analysis, the bell sounds were analyzed in regards to 127 audio features. Correlation and regression analyses were used to determine relationships between the bells' timbre ratings and the calculated audio features. Timbral changes resulting from an optimization of the bell clapper turned out to be particularly noticeable in respect to timbral brightness, the pronouncedness of the tonal components in the spectrum (harmonic energy) and the noise components (spectral flux above 1000 Hz). Specifically, by modifying the clapper, subjective pleasantness of the bells' timbre can be improved. With increasing clapper weight and decreasing ringing angle, the fundamental pitch of bells becomes more pronounced, with stronger harmonic components and less background noise.

1. BACKGROUND

The sounds of ringing bells are often difficult to rate in terms of their quality and pleasantness. Ideally, the sound of a pleasant-sounding bell should be characterized by a soft, full, and clear timbre with a fundamental, low-noise sound spectrum in which a luminously clear striking tone can be perceived with as little noise as possible¹. Since the 1950s guidelines for evaluating bell sounds have been established^{2 3 4 5}, in which the timbral brightness, the partial structure, the pitch salience of the fundamental, and the attack and release transient of the bell sound are considered. However, the final judgment of the sound of a bell often depends on the listening experience and comparative capabilities of the bell expert(s). Here the quality ratings of experts can differ considerably (see below). Signal analysis software libraries (see below) which have been used in the context of computational sound analysis over the last 15 years can be helpful for the estimation of more objective timbre features. With the help of these toolboxes, a large number of sound characteristics such as brightness, roughness, attack time, etc. can be automatically extracted from digital audio signals and further processed as numerical values. Based on these signal characteristics, it is possible to make objective comparisons between different timbres or to describe timbres as appropriately as possible by using a bundle of timbre features. These algorithms, which have been established for the description of music, sound and noise data in a wide variety of application fields, can also contribute to a comparative analysis and quality evaluation of bells.

2. RESEARCH QUESTIONS

For the reason described above, a pilot experiment was conducted. The aim of this was to investigate to which extent the sound judgments of bell experts and laypersons can be used as a basis to develop an automatic evaluation of the timbral quality and pleasantness of ringing bells. Another question was to what extent the extracted sound characteristics can be used to objectify differences between bell sounds before and after a restoration or modification, e.g. after structural changes to the clapper. Therefore, the research questions are:

- Can the perceived pleasantness and quality of church bell chimes (as rated by experts and laymen) be modeled using extracted audio signal features?
- Which sound features contribute to a perceived increase in timbre quality in a before-and-after comparison of church bells that were subjected to sound optimization procedures?

3. METHODS

In an online survey, 11 professional bell experts and 26 laypersons rated loudness-matched ringing bell sounds (8 strokes per example). Each of the 40 sound examples was presented in randomized order and evaluated using sliders between 1 and 100 points in terms of perceived quality, pleasantness, salience of the fundamental pitch, clarity, and softness of attack. The rated sound examples were analyzed with the help of software libraries for audio signal analysis^{6 7 8 9 10} with regard to 127 computable timbre features, so that on this basis correlations between the listener judgments and those extracted timbre features could be analyzed for.

4. RESULTS

When comparing the individual ratings, it becomes clear that there is little agreement among both the bell experts and the laypersons as to the extent to which the sound of a bell is of high quality or very pleasant:

Figure 1 illustrates the ratings of bell experts (orange) and laypersons (blue) with regard to the quality of the respective bell on the basis of six of the bell sounds queried in the listening test. A very variance in the ratings can be observed here. On average - considering all 40 evaluated bells - the standard deviation of the quality judgments amounts to 23.63 points. With a mean Pearson's r of 0.09, the pair-wise correlation between the individual raters is also extremely low (Krippendorff's $\alpha = 0.08$; Cronbach's $\alpha = 0.79$), although in this case slightly more consistent rating patterns can be observed among bell experts (Pearson's $r = 0.17$) than within the lay group (Pearson's $r = 0.11$).

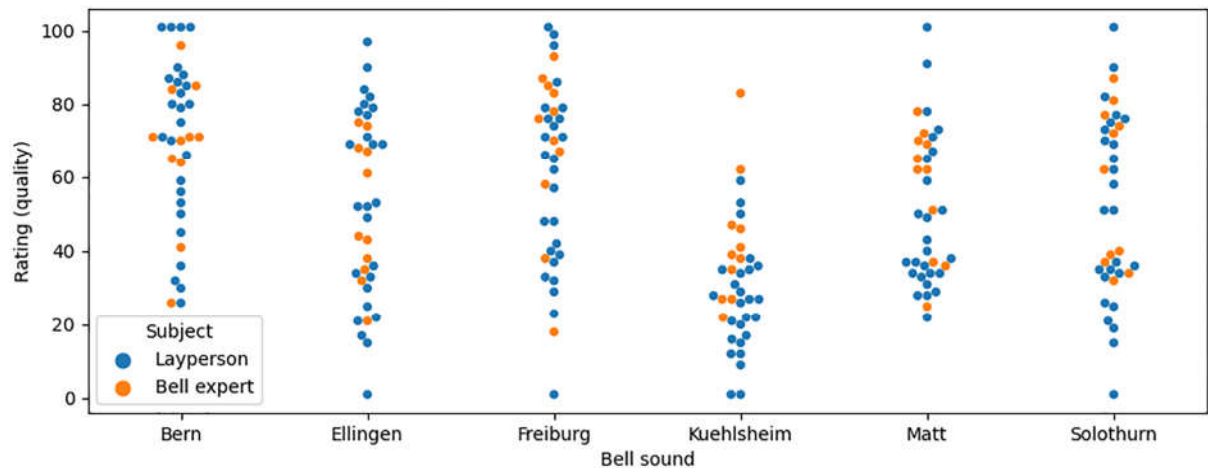


Figure 1: Quality of bell sounds rated by bell experts and laymen. Six bells are displayed exemplarily here.

Analogously, Figure 2 visualizes the significant deviations when evaluating the bell sounds according to perceived pleasantness. In this case, the mean standard deviation of the bell ratings is 22.98 points. Overall, the raters show noticeably higher agreement in their answers here, although still relatively low inter-rater reliability can be observed (Pearson's $r = 0.19$; Krippendorff's $\alpha = 0.15$; Cronbach's $\alpha = 0.889$). In this case, the inter-rater correlation turns out to be similarly low among experts (Pearson's $r = 0.22$) and laypersons (Pearson's $r = 0.23$).

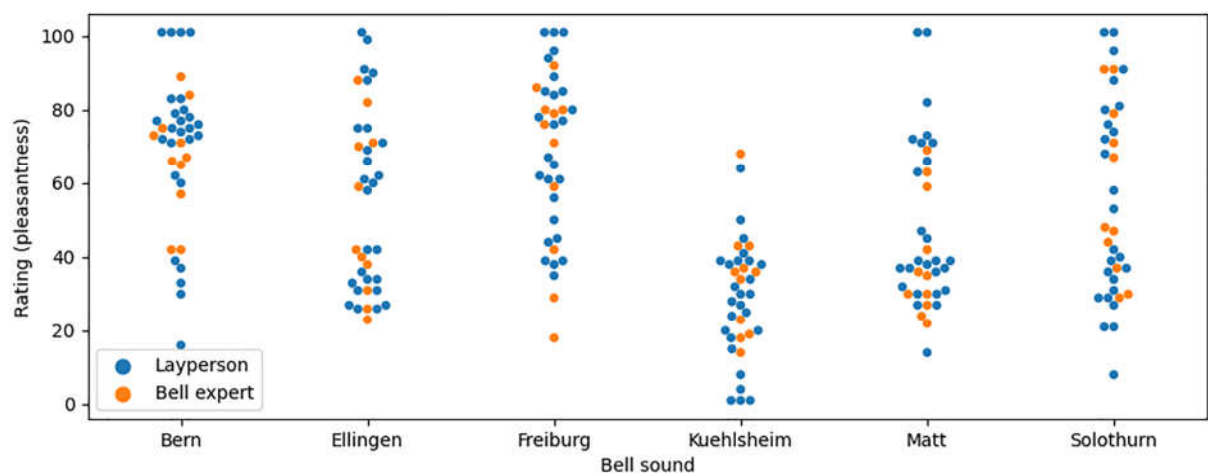


Figure 2: Pleasantness of bell sounds rated by bell experts and laymen. Six bells are displayed exemplarily here.

A. PERCEIVED QUALITY AND PLEASANTNESS OF BELL SOUNDS

Considering the observed low inter-rater agreement, the statements of the experts and laypersons studied so far are only suitable to a limited extent for the creation of a model for the evaluation of bell sound quality or pleasantness. However, with regards to the mean expert ratings positive, albeit not very strong, correlations can be seen for the quality assessment (with $p < 0.05$) with the distinctness of the minor third ($r = 0.394$) and the harmonic structure ($r = 0.391$) in the spectrum (i.e. the more pronounced the minor third as well as a harmonic structure appears in the spectrum of the bell, the higher the quality of the bell sound is judged on average) as well as a negative correlation with the tempo of the strokes ($r = -0.438$) and the clarity of the clapper impact ($r = -0.356$) (i.e., the slower the tempo of the strokes and softer the stroke, the higher the quality of the bell is rated). Via a Bayesian regression, a weak but interpretable model for the quality assessment of bell sounds can be created on the basis of the expert judgments with $R^2 = 0.376$ and $BF_{10} = 9.343$, in which especially the distinctness of the third (major thirds strength) and the harmonic structure (harmonicity strength) in the spectrum

as well as the pitch salience in the bell sound (tonal energy) and a parameter concerning the spectral shape (mfcc4) play a role (see also Figure 3).

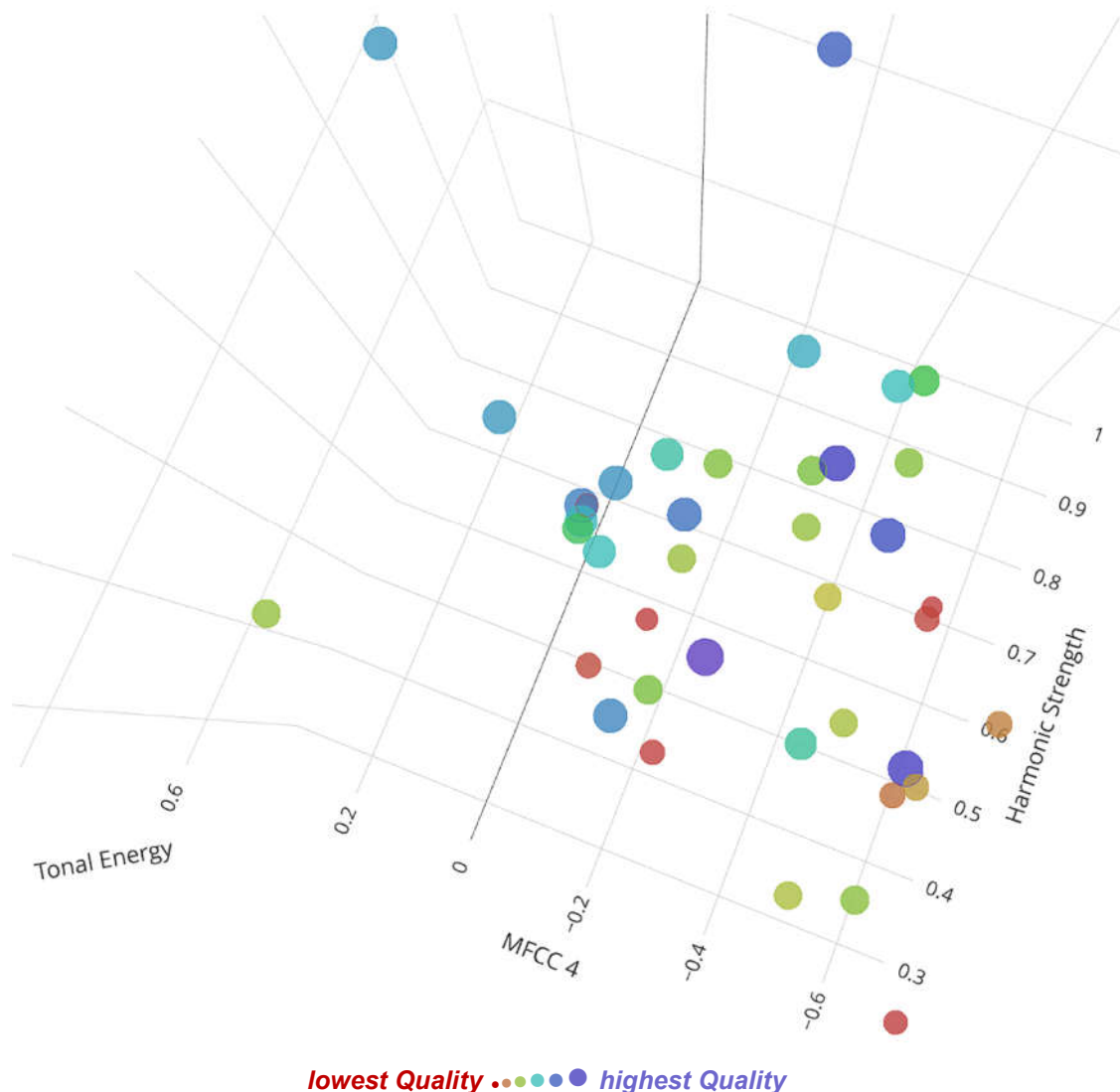


Figure 3: Quality predictors for bell sounds determined from bell experts' ratings.

The rating of the ringing bells' pleasantness shows similar results: Here, too, it is (with $p < 0.05$) the salience of the minor third ($r = 0.360$) and the harmonic structure in the spectrum ($r = 0.340$) that are associated with a more pleasant sound perception. Furthermore, the perceived pleasantness of the bell sound increases with decreasing velocity ($r = -0.459$) and decreasing timbral sharpness ($r = -0.366$). This latter relationship between decreasing timbral sharpness and increasing perceived pleasantness of bell sounds could also be observed as early as 1981 by Wolfgang Aures in his studies on the pleasantness ratings of bell sounds¹¹. A Bayesian regression based on lay and expert ratings led to a model similar to the one used for the quality assessment of bells (see above), in which the salience of the third (major thirds strength) and the harmonic structure in the spectrum (harmonicity strength) play a major role. Additionally to that – as an aspect of the tonal sharpness – the frequency position of the strongest amplitude in the spectrum contributes to this model of the pleasantness of the sound (the lower the frequency with the strongest amplitude in the spectrum, the less sharp, i.e., the more pleasant the timbre is perceived, see also Figure 4).

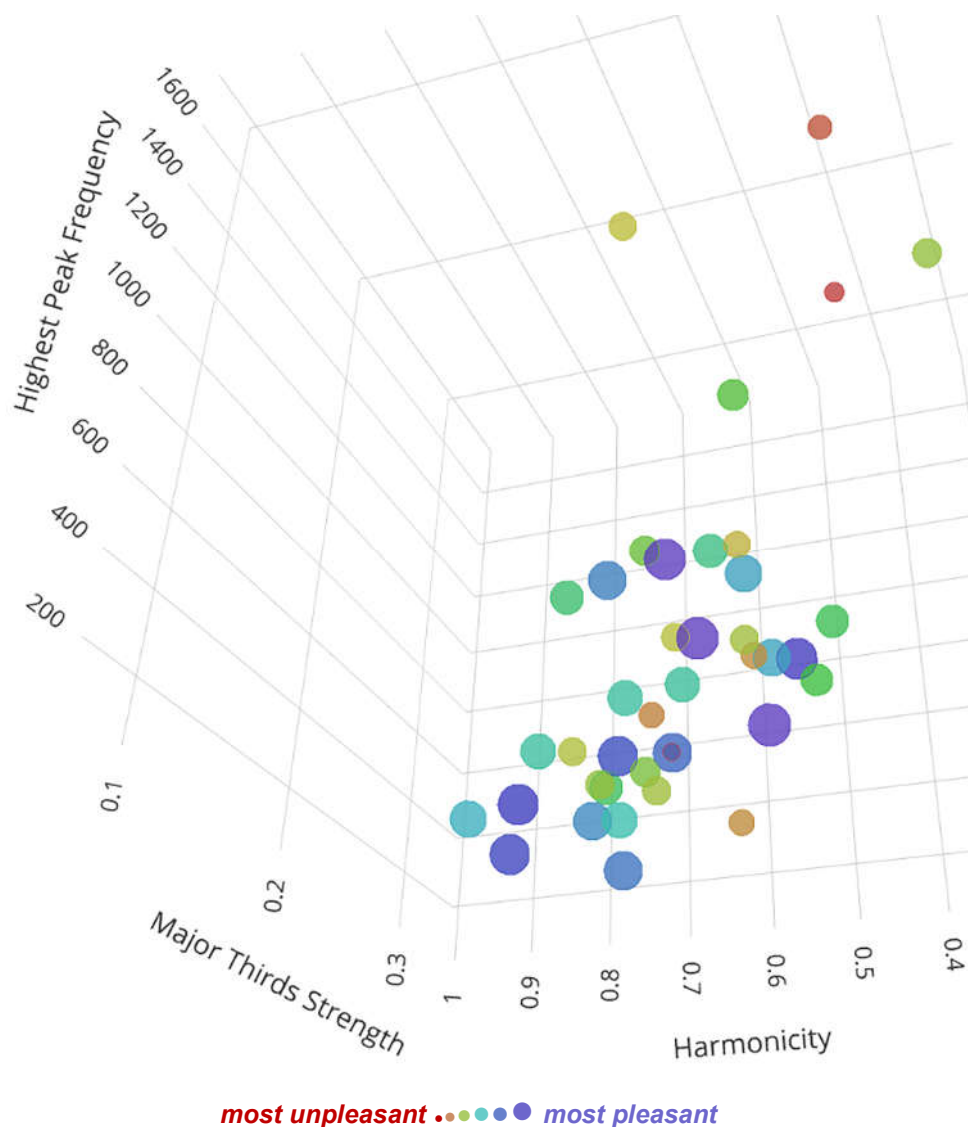


Figure 4: Pleasantness predictors for bell sounds determined from all listeners' ratings.

B. PERCEIVED CLARITY, FUNDAMENTAL PITCH SALIENCE AND SOFTNESS OF THE ATTACK

While it appeared relatively difficult to create meaningful models with high predictive power for the quality and pleasantness ratings for bells on the basis of lay and expert judgments in this first pilot test, the relations of the individual rated bell-typical sound characteristics to acoustical features seem much more clear and unambiguous: Thus, there are medium to strong correlations (with $p < 0.001$) between calculated timbral brightness and perceived clarity of bell sound ($r = 0.652$) (likewise between timbral hardness and perceived clarity, $r = 0.670$, see below. Figure 5). Similar holds for the perceived fundamental pitch salience (Figure 6): The lower the calculated timbral shrillness (high frequency content), the more pronounced the fundamental is perceived to be ($r = -0.484$). The rated fundamental pitch salience is also associated with the loudness of the tonal components involved in the sound ($r = 0.504$) as well as with the attack time of the bell sound ($r = 0.413$): The longer the clapper remains on the bell when it is struck, the fewer vibrating modes can be produced, and the more fundamental or dull the spectrum becomes.

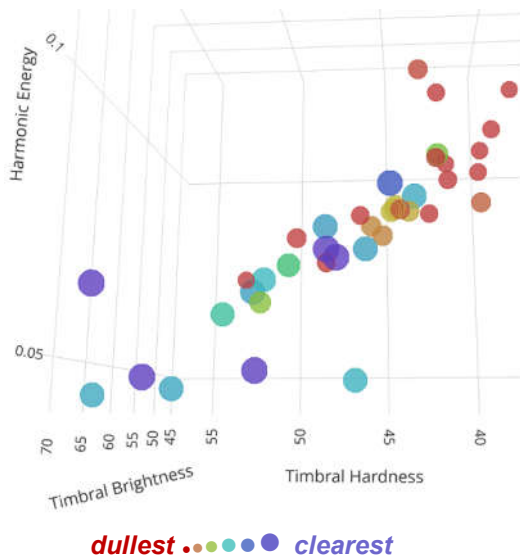


Figure 5: Timbre features to describe the perceived clarity of bell sounds.

The same applies to the identified timbre features in the case of the description of the perceived softness of the bell strike, which is rated as increasingly soft with decreasing timbral hardness ($r = -.530$) and decreasing regularity of the percussive component in the spectrum ($r = -.520$), as well as with an increasing skewness in the energy distribution in the spectrum toward the higher frequencies (spectral skewness, $r = 0.616$). This means, the less pronounced the proportion of broadband (percussive) frequency components (i.e. the duller the sound), the softer the bell strike is perceived (see Figure 7).

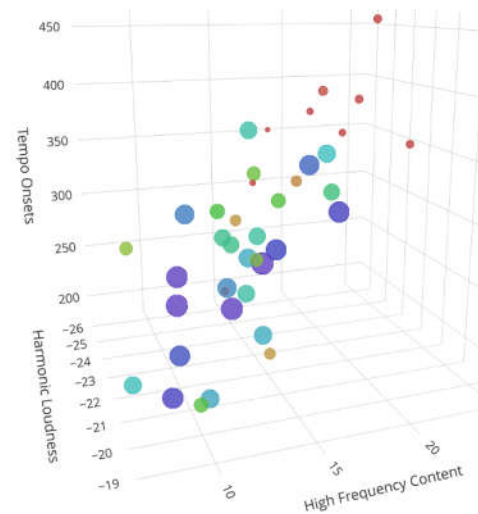


Figure 6: Timbre features to describe the perceived fundamental pitch salience

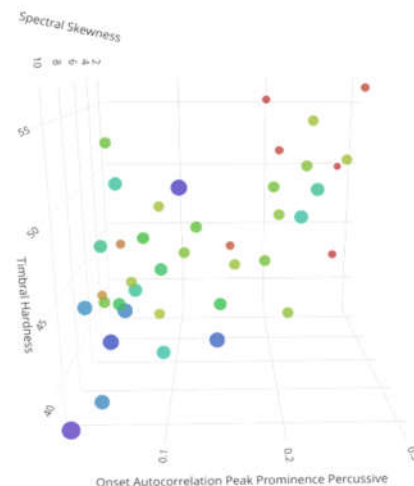


Figure 7: Timbre features to describe the perceived softness of the attack transient

C. PERCEIVED SOUND IMPROVEMENTS AFTER STRUCTURAL OPTIMIZATION OF THE CLAPPER

Optimization of the clapper to extend the durability of the bell is often accompanied by a drastic change in timbre^{12 13}. The timbral changes resulting from the structural modifications are usually rated as a significant improvement by both laypersons and bell experts in a before-and-after comparison. Thus, after the optimization of the clapper the 37 laymen and experts perceived the sound of the bells of the churches in Thun (Reformed City Church, bell 1, pitch: A3), Reichenau-Mittelzell (Minster, bell 2, pitch: E4), Ellingen (St. Georg, bell 1, pitch B3) and Bern (Minster, bell 6, pitch E4) as significantly more pleasant on a scale of 1 to 100 in most cases (see table 1).

Table 1. Pleasantness ratings by experts and laymen with one-sided Wilcoxon signed-rank test over all ratings of the respective bell before and after clapper optimization.

Pleasantness (1-100)	Experts (mean values)	Laymen (mean values)	All (mean values)
Thun, City Church (A3)	(before) 44 -> 74 (after) W = 3**; p = 0.00382	(before) 51->71 (after) W = 50**; p = 0.00123	(before) 49->72 (after) W = 79***; p = 0.00003
Reichenau, Minster (E4)	(before) 45 -> 64 (after) W = 7*; p = 0.01037	(before) 55->68 (after) W = 86*; p = 0.01975	(before) 52->67 (after) W = 144.5**; p = 0.00153
Ellingen, St. Georg (B3)	(before) 52 -> 65 (after) W = 13*; p = 0.03768	(before) 56->62 (after) W = 97; p = 0.0649	(before) 55->63 (after) W = 179*; p = 0.01294
Bern, Minster (E4)	(before) 55 -> 66 (after) W = 8*; p = 0.02336	(before) 62->70 (after) W = 147; p = 0.23448	(before) 60->69 (after) W = 231.5; p = 0.05533

This rating is reflected in the change of mainly three timbre features: After a specific adjustment of the clapper, the bell sounds also prove to be more fundamental and less shrill ($t=-4.472$; $p>0.01$), less noisy (spectral flux above 1000 Hz, $t=-10.795$; $p < 0.001$) and more strongly characterized by harmonic components in the spectrum (harmonic energy, $t=4.443$; $p < 0.01$).

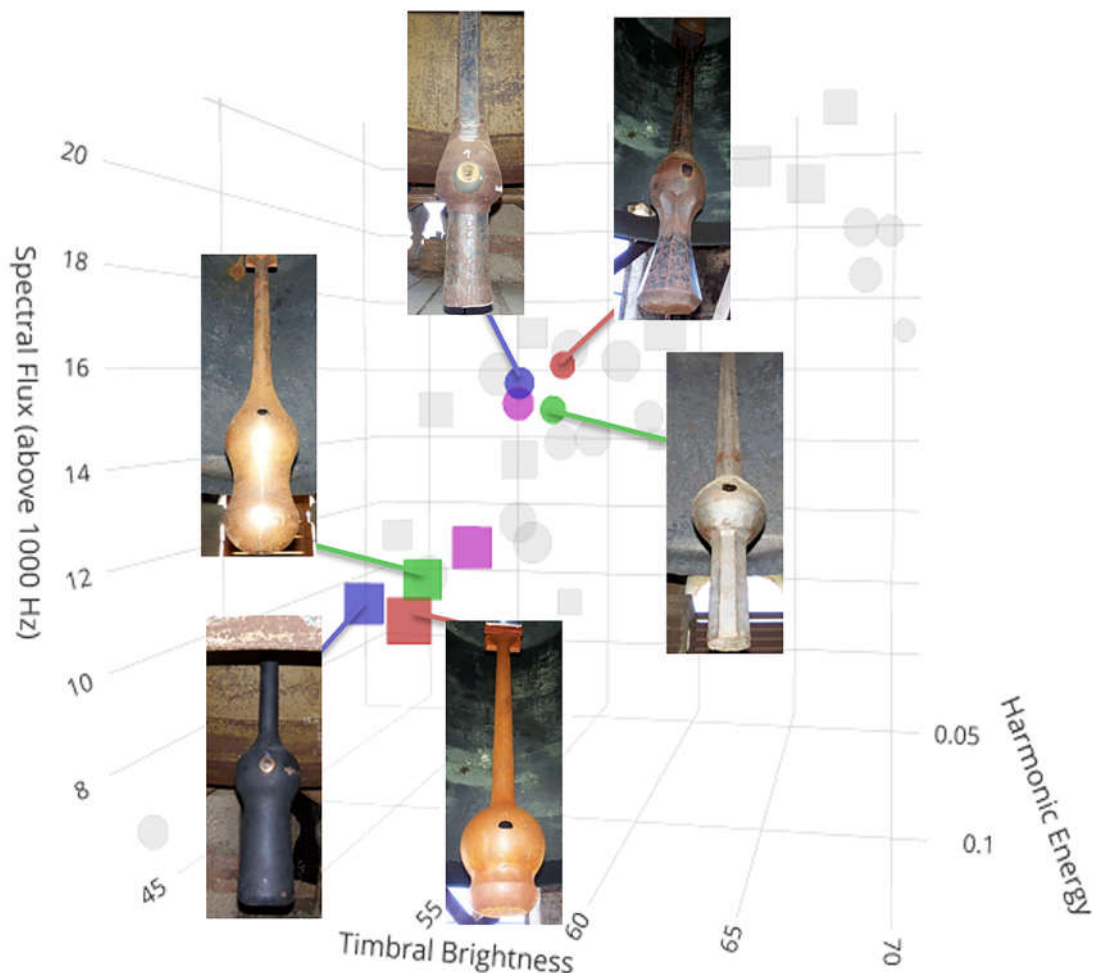


Figure 8: Optimized clappers and their calculated timbre features before (●) vs. after (■) optimization: Thun, Reformed City Church, bell 1 (A3), Reichenau-Mittelzell, Minster, bell 2 (E4), Ellingen, St. Georg, bell 1 (B3), Bern, Minster, bell 6 (E4). The larger the symbol the more pleasant the timbre impression.

D. STRUCTURAL AND TIMBRAL CHARACTERISTICS FOR THE SENSATION OF A PLEASANT BELL SOUND.

These three sound characteristics (fundamental pitch salience or low brightness/shrillness, low noise and prominent harmonic structure) are also shown to be particularly significant when related to other constructional characteristics of the bell: thus, in agreement with the calculated timbre features, the sound is perceived as more pleasant with increasing bell diameter (and thus lower striking pitch), increasing bell mass and bell ring thickness. The same applies to the design and hanging of the clapper:

Table 2: Correlations of bell characteristics with timbre features leading to a pleasant bell timbre impression (with $p < 0.01$).

Correlation with	Brightness/Shrillness (r)	Harmonic Energy (r)	Spectral Flux (r)
Bell diameter	-0.859	0.782	-0.683
Bell ring thickness	-0.846	0.788	-0.686
Bell mass	-0.709	0.656	-0.583
Clapper bale diameter	-0.785	0.691	-0.687
Clapper mass	-0.635	0.557	-0.578
Ringling angle	0.661	-0.589	0.511

With increasing clapper bale diameter, greater mass, and decreasing ringling angle, the speed of the clapper's approach to the bell decreases more and more, making the resulting sound more fundamental (less shrill/bright), less noisy, and more pronounced in its harmonic structure.

5. CONCLUSION

Thus, although the data collected and presented here cannot yet be used to establish robust final models for an objective estimation of the quality of or the pleasantness of bell sounds (for this purpose, further and, above all, more consistent ratings by laypersons and experts would be necessary), numerous relationships between structural properties and the perceived pleasantness of bell timbres can be identified, above all with the help of timbre features like fundamental pitch salience, timbral brightness/shrillness, harmonic energy (prominent harmonic structure in the spectrum), and spectral flux (as little noisiness as possible).

REFERENCES

- 1 Wernisch, J. (2006). Glockenkunde von Österreich. Lienz: Journal Verlag (pp. 8–11).
- 2 Limburger Richtlinien für die klangliche Beurteilung neuer Glocken (1951), in K. Kramer (1986), Glocken in Geschichte und Gegenwart. Karlsruhe: Badenia.
- 3 Thienhaus, E. (1952). Definitionen zur Glockenprüfung. *Acustica* 2, pp. 251–253.
- 4 Ellerhorst, W., & Klaus, G. (1957). Handbuch der Glockenkunde. Weingarten: Martinus.
- 5 Weissenbäck, A., & Pfundner, J. (1961). Tönendes Erz. Graz, Köln: Böhlhaus.
- 6 Lartillot, O., Toivianen, P., & Eerola, T. (2008). A Matlab toolbox for music information retrieval. In C. Preisach, H. Burkhardt, L. Schmidt-Thieme, & R. Decker (Eds.). *Data analysis, machine learning and applications* (pp. 261–268). Berlin, Heidelberg: Springer.
- 7 Bogdanov, D., Wack, N., Gómez, E., Gulati, S., Herrera, P., Mayor, O., Roma, G., Salamon, J., Zapata, J.R., & Serra, X. (2013). Essentia: an audio analysis library for music information retrieval. In *Proceedings of the 14th ISMIR conference* (pp. 493–498), Curitiba.
- 8 McFee, B., Raffel, C., Liang, D., Ellis, D.P., McVicar, M., Battenberg, E., & Nieto, O. (2015). Librosa: Audio and music signal analysis in python. In *Proceedings of the 14th python in science conference* (pp. 18–25), Austin.
- 9 Pearce, A., Brookes, T., & Mason, R. (2017). Timbral attributes for sound effect library searching. *AES international conference on semantic audio*, 22–24 June 2017, Erlangen, Germany.
- 10 Lartillot, O. (2019). Miningsuite: A comprehensive Matlab framework for signal, audio and music analysis. In *Proceedings of the 16th SMC* (pp. 489–489), Málaga.
- 11 Aures, W. (1981). Wohlklangsbeurteilung von Kirchenglocken. In *Fortschritte der Akustik, DAGA81 Berlin* (pp. 733–736), Berlin: VDI-Verlag.
- 12 Rupp, A., & Plitzner, M. (2018). Läueteoptimierung zur Schonung von Glocken. In *Proceedings of the 2. Bell Symposium, ECC-ProBell 2018* (pp. 29–43). Göttingen: Cuvillier.
- 13 Rupp, A., Spiess, D., & Plitzner, M. (2018). Simulation des Klöppelanschlags – Einfluss der Klöppelgestaltung auf den Klang. In *Proceedings of the 2. Bell Symposium, ECC-ProBell 2018* (pp. 83–99). Göttingen: Cuvillier.